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Dye-doped cholesteric liquid crystal light shutter with a polymer-dispersed liquid crystal film

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ABSTRACT

A light shutter, which consists of a dye-doped cholesteric liquid crystal (ChLC) layer and a polymer-dispersed liquid crystal (PDLC) film, for simultaneous control of haze and transmittance is demonstrated. In the opaque state, it can not only provide a black color by using the dye-doped ChLCs but also hide the objects behind the display panel by using the PDLC film. The proposed light shutter shows a high haze value of 90.7% with a low specular transmittance of 1.20%. By switching the proposed light shutter placed at the back of a see-through display, we can choose between the see-through mode and the high-visibility mode in a see-through display.

1. Introduction

See-through displays are considered as one of the highly promising next-generation displays [1–4]. Currently, a see-through display using organic light-emitting diodes (OLEDs) are being widely studied [2–4]. However, a see-through display using OLEDs cannot represent black color because each pixel includes a transparent window area. Therefore, a see-through display using OLEDs has poor visibility characteristics. To overcome these drawbacks, a light shutter is placed at the back of a see-through display. To realize a high-visibility see-through display, it is necessary to use light scattering and absorption effects simultaneously to hide the objects behind the display panel and provide the black color. Light shutters that uses both effects simultaneously, such as dye-doped polymer-networked liquid crystal (PNLC) [5–7] and dye-doped cholesteric liquid crystal (ChLC), have been reported recently [8–12]. However, light shutters that use dye-doped ChLC or dye-doped PNLC exhibit a rather high transmittance in the opaque state because dichroic dye molecules are not aligned parallel to the substrate.

Recently, our group proposed a light shutter device using two ChLC cells [12]: a light-scattering cell and a light-absorption cell. Although this double-cell light shutter has low transmittance in the opaque state because the dye molecules are aligned parallel to the substrate, it suffers from disadvantages that include low transmittance in the transparent state, high thickness, and high fabrication cost because of the double-cell structure. Thus, for practical application of a light shutter in a see-through display, a single-cell light shutter in which dye molecules are aligned parallel to the substrates is desirable.

In this paper, we demonstrate a dye-doped ChLC light shutter containing a PDLC film within a single cell. The proposed light shutter can provide light absorption and scattering simultaneously, which in turn results in low transmittance with high haze in the opaque state. We expect that the proposed light shutter can be used widely for see-through displays that can hide the objects behind the display panel while providing the black color.

2. Principle of operation

The structure of a dye-doped ChLC light shutter with a PDLC film is shown in Fig. 1. For absorption of the incident light, we use dichroic dyes. Dye molecules are convenient for switching because they are easily aligned by LC molecules [5–12]. When the polarization direction of the incident light is parallel with the absorption axis of dye molecules, the incident light is strongly absorbed. Conversely, the incident light is weakly absorbed when the direction of polarization is perpendicular to the absorption axis. To absorb the incident light regardless of polarization direction, we can use dye-doped ChLCs, which have a helical structure [10]. For

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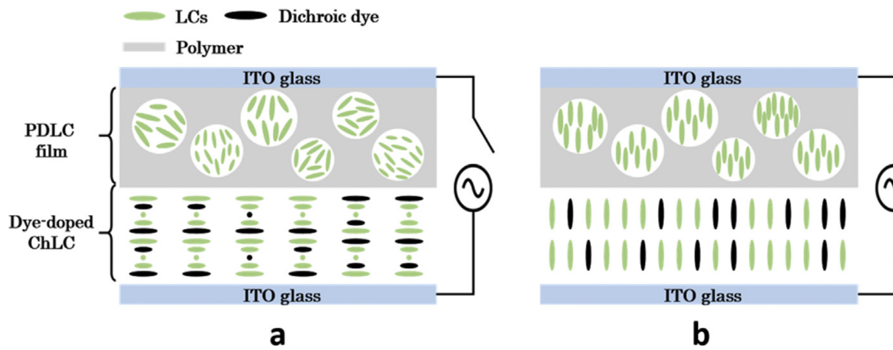

Fig. 1. Structure and operation of the proposed light shutter in the (a) opaque and (b) transparent states.

scattering of the incident light, we use a PDLC film, which can scatter the incident light owing to the refractive index difference between the LC and the polymer [13,14].

The operation of a dye-doped ChLC light shutter with a PDLC film is shown schematically in Fig. 1. It is switchable between the opaque and transparent states. The opaque state can be realized using absorption by the dye-doped ChLCs and scattering by the PDLC film. In the opaque state, the incident light is absorbed by dye molecules and backward- and forward-scattered by the PDLC film. To switch to the transparent state, we apply a vertical electric field between the top and bottom electrodes. In the transparent state, light absorption is minimized in the dye-doped ChLC because it is switched to the homeotropic state so that the incident light is weakly absorbed by dye molecules [10]. Moreover, light scattering by the PDLC film is minimized because the LC molecules inside the film are aligned parallel to a vertical electric field so that the refractive indices of the LC and polymer are the same.

3. Cell fabrication

To verify the electro-optical characteristics of the proposed light shutter, a dye-doped ChLC cell with a PDLC film was fabricated. To prepare a PDLC film, we mixed positive LC (E7, Δn: 0.223; $\Delta\varepsilon$: 13.5) with UV curable monomer (NOA65, Norland Products). We studied the characteristics of the fabricated PDLC films as a function of the monomer concentration and the intensity of UV light.

We introduced total, specular, and diffuse transmittance and haze for evaluation of the optical performance. The specular [diffuse] transmittance T_s [T_d] refers to the ratio of the power of the beam that emerges from a sample cell, which is parallel (within a small range of angles of 2.5°) [not parallel] to a beam entering the cell, to the power carried by the beam entering the sample. The total transmittance T_t is the sum of the specular transmittance T_s and the diffuse transmittance T_d. The haze H can be calculated as $H = T_d/T_t$.

Fig. 2(a) depicts the total transmittance and haze of PDLC films as a function of the monomer concentration. The maximum haze value was obtained with 40 wt% of UV-curable monomer. Fig. 2(b) depicts the total transmittance and haze of PDLC films as a function of the UV intensity with 40 wt% of UV curable monomer. As the intensity of UV light was increased, the measured total transmittance decreased because of the increase in backward scattering. When the UV intensity was greater than 100 mW/cm^2, the haze value rapidly decreased. The fabrication condition was chosen as

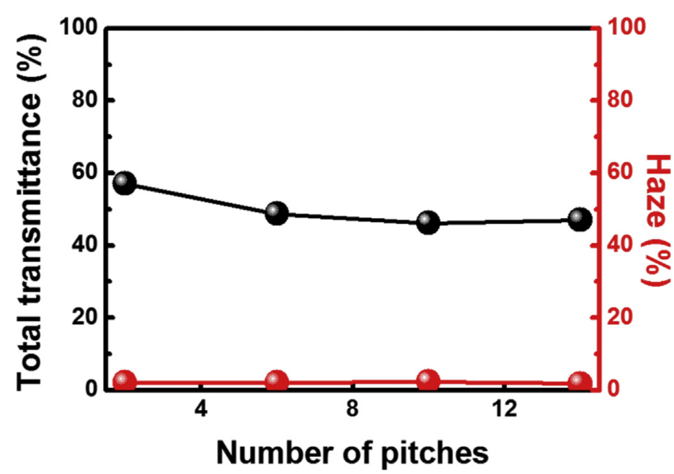

Fig. 3. Total transmittance and haze versus number of pitches.

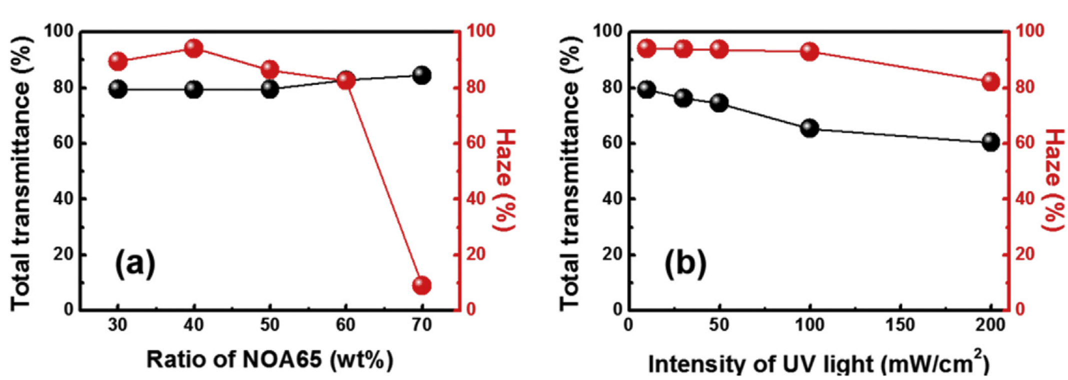

Fig. 2. Total transmittance and haze versus (a) the ratio of NOA65 and (b) the intensity of UV light.